The Origin of Thermal Ionisation from Carbon.

By O. W. Richardson, M.A., D.Sc., F.R.S.

(Received November 25, 1913,—Read January 29, 1914.)

In the 'Proceedings'* Dr. J. N. Pring describes interesting experiments designed to throw light on the origin of thermal ionisation from carbon. These experiments form a continuation of earlier experiments along similar lines by J. N. Pring and A. Parker.† In commenting on the results of the earlier work, Dr. Pring says:—

" It has been shown by the present writer, in conjunction with A. Parker, that the ionisation which is produced by carbon at high temperatures, and in presence of gases at low pressures, is reduced to a much smaller order of magnitude by eliminating impurities from the carbon, and by exhausting to a high degree the containing vessel.

" *The results throw considerable doubt on the whole basis of the theory of electronic emission from incandescent solids.*

" According to this theory,‡ the ionisation produced by elements at high temperatures is due to the escape of free electrons, which pass into the surrounding space on account of the kinetic energy acquired at the high temperature.

" It was shown, however, in the above work that in the case of carbon this ionisation *is probably related to some chemical action* or some intermediate effect *exerted by the gas in contact with the solid.*"

In the summary and conclusions at the end of the later paper Dr. Pring states:—

" *It is clear from these results that the thermal ionisation ordinarily observed with carbon is to be attributed to chemical reaction between the carbon and the surrounding gas.*

" While it is difficult to prove definitely that there is no electronic emission from the heated carbon itself, *it is obvious that it is exceedingly small compared with ionisation which can be attributed to ordinary chemical change.*"

The object of the present note is to point out certain conditions affecting the arrangement of apparatus used by these authors which make it quite certain, in the opinion of the present writer, that none of the statements

* 'Roy. Soc. Proc.,' A, vol. 89, p. 344 (1913).

† 'Phil. Mag.,' vol. 23, p. 199 (1912).

"‡ Richardson, 'Phil. Trans.,' 1903, A, vol. 201, p. 497; 'Phil. Mag.,' 1912, vol. 24 pp. 737–744; *ibid.*, 1913, vol. 26, p. 345."

italicised above can be regarded as a valid inference from the results of the experiments in question. In the discussion which follows, the numerical values refer to the apparatus figured in Dr. Pring's paper in the 'Proceedings,' although the objections apply with at least equal force to the arrangement used in the earlier experiments of Pring and Parker.

The apparatus used in these researches differs in two very important respects from that which has been employed by other workers in the same field. The size of the hot solid is very much greater than usual, and the current required to heat it is correspondingly bigger. Under these conditions the effect of the magnetic field arising from the heating current is quite important; and when this is taken into account the phenomena recorded can certainly not be said to contravene the requirements of the ordinary theory of electronic emission.

In the experiments under consideration a hollow carbon rod, 0·5 cm. in diameter and 8 cm. long, was the source of negative emission. To heat it to a temperature of 1850° a current of 80 ampères was required. The leakage from the hot rod to a small disc, placed 8 cm. away from the rod in the equatorial plane, was measured. Potential differences up to 220 volts could be applied between the rod and the insulated disc.

The geometry of this arrangement is so complex that it is impossible to make definite numerical statements as to the distribution of the electric intensity. It will, however, be sufficient for our purpose to consider a somewhat similar system, in which the disc is replaced by a cylindrical conducting surface coaxial with the hot rod. The electric intensity is then radial and, at a distance r from the axis, is, in electromagnetic units,

$$\mathrm{R} = \frac{\mathrm{V}_1 \times 10^8}{r(\log b - \log a)}, \tag{1}$$

where V_1 is the potential difference in volts between the rod and the cylinder, a is the radius of the rod, and b the radius of the cylinder. The magnetic intensity H is in circles about the axis and, at a radial distance equal to r, is given by the equation

$$\mathrm{H} = \frac{2i}{10r}, \tag{2}$$

where i is the current through the rod in ampères. The motion of an electron starting with zero velocity at the surface of the rod is in planes containing the axis, under this system of forces. It is determined by the equations

$$m\frac{\partial^2 r}{\partial t^2} = \mathrm{R}e - \mathrm{H}e\frac{\partial z}{\partial t} \tag{3}$$

and

$$m\frac{\partial^2 z}{\partial t^2} = \mathrm{H}e\frac{\partial r}{\partial t}. \tag{4}$$

These may be written

$$m\frac{\partial^2 r}{\partial t^2} = \frac{Ae}{r} - \frac{Be}{r}\cdot\frac{\partial z}{\partial t} \tag{5}$$

and

$$m\frac{\partial^2 z}{\partial t^2} = \frac{Be}{r}\cdot\frac{\partial r}{\partial t}. \tag{6}$$

m is the mass of an electron, z is the distance parallel to the axis

$$A = \frac{V_1 \times 10^8}{\log b - \log a}, \quad \text{and} \quad B = \frac{i}{5}. \tag{7}$$

From (6)

$$\frac{\partial z}{\partial t} = \frac{Be}{m}\log\frac{r}{a}, \tag{8}$$

if $\partial z/\partial t = 0$, when $r = a$.

After elimination of z from (5) by means of (8), the first integral of (5) is seen to be

$$\left(\frac{\partial r}{\partial t}\right) = \left(\frac{2}{m}\log\frac{r}{a}\right)\times\left(Ae - \tfrac{1}{2}\frac{B^2e^2}{m}\log\frac{r}{a}\right) = \left(\frac{Be}{m}\log\frac{r}{a}\right)^2\left(\frac{\partial r}{\partial z}\right)^2, \tag{9}$$

subject to $\partial r/\partial t = 0$, when $r = a$.

It follows from (9) that the maximum distance r_m which an electron can travel away from the axis is given by

$$r_m = ae^{2mA/B^2e} = ae^{(2V_1 \times 10^8 \times 25)/[\log(b/a) \times (e/m) \times i^2]}. \tag{10}$$

In one of Dr. Pring's experiments the values of the quantities entering into the exponent were, at 1850°,

$$V_1 = 220, \qquad b = 8, \qquad a = 0{\cdot}25, \quad \text{and} \quad i = 80.$$

The value of e/m is $1{\cdot}76 \times 10^7$ electromagnetic units, so that even under the relatively favourable conditions contemplated, the maximum distance which an electron could travel from the axis would be

$$r_m = 4{\cdot}19 \text{ cm.}$$

This distance increases rapidly as the heating current diminishes, so that when the heating current is 57 ampères the distance becomes about 62 cm., instead of 4·19 cm. Thus, if the conditions which held during the experiment were exactly those contemplated in these calculations, the electrons would only be prevented from reaching the electrode with the largest heating currents which were used.

But the actual conditions, in the experiments referred to, are much less favourable to the escape of electrons than those which we have assumed. The collecting electrode was of comparatively small size, so that most of the potential fall would occur in its immediate neighbourhood and the electric field near the rod would be greatly weakened. Even so, the relatively strong

part of the field would be confined to the equatorial region; there would be very little near the ends. Moreover, the glass bulb would tend to acquire a negative charge, which would help to shield the rod from the field arising from the positively charged electrode. Finally, any electron which found itself in the region occupied by the relatively strong electrostatic field would quickly be deflected out of this region by the action of the magnetic field.

Thus, in the experiments with the larger currents, none of the emitted electrons would be able to travel a distance from the axis equal to half the distance of the collecting electrode, and very few would be able to travel away a distance comparable with this. Even with the (presumably) smaller heating currents employed at the lower temperatures, one cannot be certain that there ought to be any measurable leakage in these experiments arising from electronic emission. Conclusions drawn from these calculations are valid only at the very lowest pressures, when the amount of gas present is too small to affect either the nature of the ions or their motion.

It remains to consider whether it is necessary to attribute to chemical action the origin of the increased currents which are observed when traces of different gases are present. There are at least two ways in which the presence of a gaseous atmosphere would influence the number of ions collected by the positive electrode. The first of these is by the mechanical interference of the molecules with the motion of the ions through mutual collisions. This kind of effect would undoubtedly produce a large increase in the current received if the pressure were increased by very considerable amounts; but one would hardly expect it to be important at pressures below 0·005 mm., where the mean free path of an electron is comparable with 10 cm. in the simpler gases. The second way is by direct combination of the electrons with the molecules and atoms of the surrounding gas. This would result in the formation of ions possessing masses of atomic magnitude and correspondingly smaller values of e/m. These ions would not be deviated appreciably by the magnetic fields, but would follow the lines of electric force fairly closely until they reached the positive electrode. This explanation of the nature of the currents observed by Dr. Pring at very low pressures is supported by the order of comparative efficiency of the different gases, as well as by the large specific effects produced by such small quantities of gas. The order is, in fact, very much the same as that found by Sir J. J. Thomson* for the relative frequency of occurrence of the corresponding negatively charged atoms and molecules in the positive rays.

It may be well to add that the currents at the higher temperatures cannot be due simply to the emission of *electrons* from the hot carbon under the

* 'Roy. Soc. Proc.,' A, vol. 89, p. 1 (1913).

influence of chemical action, unless the nature or motion of the emitted electrons is modified subsequently in some such way as that outlined. For the calculations given above have shown that such electrons would never reach the collecting electrode. In any event if chemical action were the determining factor one would rather expect the effect of carbon dioxide to be of a different order from that of any of the other gases investigated.

It seems probable that chemical action does influence the phenomena under consideration in another way, and that the number of heavy ions formed is determined by a reaction between the electrons liberated from the carbon and the products of the action of the surrounding gas on the hot carbon. This is quite different from supposing that the electrons are emitted as a consequence of the action of the gases on the carbon. It may be that there is an emission of electrons from carbon which is stimulated directly by chemical action, but there is, so far as the writer is able to judge, no experimental evidence at present which would compel us to accept this as an established fact.

The most important conclusions which would seem to follow from the foregoing discussion are :—

1. In those of the experiments in question in which heating currents in the neighbourbood of 80 ampères were employed, and temperatures in the neighbourhood of 1800° C. or higher were attained, none of the electrons emitted by the carbon would reach the collecting electrode, at the lowest pressures.

2. Owing to the geometrical arrangement of the apparatus, which does not lend itself to exact calculation, it is impossible to say what proportion of the emitted electrons would reach the electrode when the smaller heating currents were used, at low pressures. In any event, it cannot be said with certainty, judging from such data as are at present available, that the minimum currents observed by Dr. Pring at 1200° C. are smaller than those which would be called for by the ordinary thermionic theory. It is only the currents at the higher temperatures which seem definitely out of line, and the smallness of these is readily accounted for by the magnetic deflection.

3. An increase of the observed currents with increasing gas pressure is to be expected on account of—

(*a*) The interference of the gas molecules with the motion of the electrons; and

(*b*) The combination of the electrons with atoms and molecules of the gases.

The large specific effects produced by traces of different gases seem to indicate that (*b*) may be an important factor.

4. The experiments cannot be held either to prove that the emission of electrons from hot carbon is an immediate consequence of chemical action between the carbon and the surrounding gases: or to invalidate those theories which regard this effect as a physical property of the hot solid.

The Magnetic Properties of Iron when Shielded from the Earth's Magnetism.

By Ernest Wilson.

(Communicated by Prof. J. A. Fleming, F.R.S. Received January 10,—Read February 26, 1914.)

The primary object of the experiments described in this paper is to examine the magnetic properties of iron under small magnetic forces when shielded from the earth's magnetism. In a previous paper* experiments were described in which these magnetic properties were examined at low forces, and hysteresis loops obtained at maximum values of the magnetic induction as low as 0·937. The specimen, which was of the same material as used in the present experiments, was exposed to the influence of the earth's magnetism, and it is this influence which has now been removed as far as possible.

The specimen is of ring form and is built up to an axial length of 38·8 cm. of stampings of an alloy of iron known as "Stalloy," containing 3 per cent. of silicon. The internal and external diameters of each stamping are 7·6 and 12·75 cm. respectively, and the thickness varies from 0·34 to 0·14 cm. The secondary winding is next to the stampings and has 177 turns of copper wire 0·81 mm. diameter insulated by cotton impregnated with paraffin. The primary or magnetising winding has 10 turns of copper strip 19 mm. wide and 0·13 mm. thick covered with insulating tape.

The shield is built up to a length of 47 cm. of stampings of transformer iron 0·62 mm. thick. The internal and external diameters of each stamping are 30·5 and 40·6 cm. respectively. At each end are discs of soft iron 40·6 cm. diameter which together with two square end plates make up an overall length of 56 cm. The shield is firmly clamped by four bolts passing through

* 'Roy. Soc. Proc.,' A, vol. 80, p. 548 (1908).